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IS 15086-1 (2001): Surge Arresters, Part 1: Non-Linear Resistor Type Gapped Surge Arresters for a.c. Systems [ETD 30: Surge Arresters]

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IS 15086 (Part 1) : 2001
IEC 60099-1 (1991)
[Superseding IS 3070 (Part 1) : 1985]

भारतीय मानक

प्रोत्कर्ष निरोधक

भाग 1 ए. सी. प्रणाली के लिए अरैखिक प्रतिरोधक टाइप अन्तराल प्रोत्कर्ष निरोधक

Indian Standard

SURGE ARRESTERS

PART 1 NON-LINEAR RESISTOR TYPE GAPPED SURGE ARRESTERS FOR a.c. SYSTEMS

ICS 29.120.50;29.240.10

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BUREAU OF INDIAN STANDARDS
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI 110002

December 2001

Price Group 12

NATIONAL FOREWORD

This Indian Standard (Part 1) which is identical with IEC 60099-1 (1991) 'Surge arresters — Part 1 : Non-linear resister type gapped surge arresters for a.c. systems' issued by the International Electrotechnical Commission (IEC), was adopted by the Bureau of Indian Standards on the recommendation of the Surge Arrestors Sectional Committee and approval of the Electrotechnical Division Council.

The text of IEC Standard has been approved as suitable for publication as Indian Standard without deviations. Certain conventions are, however, not identical to those used in Indian Standards. Attention is particularly drawn to the following:

a) Wherever the words 'International Standard' appear referring to this standard, they should be read as 'Indian Standard'; and

b) Comma (,) has been used as a decimal marker while in Indian Standards, the current practice is to use a point (.) as the decimal marker.

With the publication of this standard, IS 3070 (Part 1) : 1985 'Specification for lightning arresters for alternating current systems: Part 1 Non-linear resistor type lightning arresters (*second revision*)' shall be withdrawn.

CROSS REFERENCES

In this adopted standard, references appear to certain International Standards for which Indian Standards also exist. The corresponding Indian Standards which are to be substituted in their respective places are listed below along with their degree of equivalence for the editions indicated:

International Standard	*Corresponding Indian Standard*	*Degree of Equivalence*
60060-1 High-voltage test techniques	IS 2071 (Part 1) : 1993/IEC 60001-1 (1989) High voltage test techniques : Part 1 General definitions and test requirements (*second revision*)	Identical
60071-2 : 1996 Insulation co-ordination — Part 2 : Application guide	IS 3716 : 1978 Application guide for insulation co-ordination (*first revision*)	Equivalent
60099-3 : 1990 Surge arresters — Part 3: Artificial pollution testing of surge arresters	Nil	—

For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test, shall be rounded off in accordance with IS 2 : 1960 'Rules for rounding of numerical values (*revised*)'. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

Only the English text of the International Standard has been retained while adopting it in this Indian Standard.

AMENDMENT NO. 1 SEPTEMBER 2011

TO

IS 15086 (Part 1) : 2001/IEC 60099-1 (1991) SURGE ARRESTORS

PART 1 NON-LINEAR RESISTOR TYPE GAPPED SURGE ARRESTORS FOR a.c. SYSTEMS

(The Amendment was originally published by IEC in 1999.)

Page 6

3.1 Arrester identification

Replace the 5th dash "pressure-relief class (for arresters fitted with pressure-relief devices)" *by the following new text:*

– the rated short-circuit withstand current in kiloamperes shall be stated on the nameplate of the surge arrester. Arresters without a claimed short-circuit withstand capability shall have this indicated on the nameplate, see 8.7.

Page 8

5.4 Switching impulse sparkover voltage

Replace the second sentence of this clause by the following new text:

There are limits only for heavy-duty arresters with rated voltages above 200 kV. For these arresters the limits are given in table 8 (column 7).

Page 9

5.8 Long-duration current withstand

Replace the second sentence of this clause by the following new text:

For both types the lightning residual voltage (8.4.1) recorded before and after this test shall not have changed by more than ±10 %. For heavy surge arresters, the dry power frequency sparkover voltage (8.2) recorded before and after the test shall not have changed by more than ±10 %.

Page 11

Table 2 – Parameters for wet tests

Replace characteristics 4 and 5 including the note, as follows:

Price Group 5

4. Type of nozzle	See figures 2a, 2b, 2c*	See figure 2d*
5. Water pressure	See figures 2a, 2b, 2c*	See figure 2d*
* Figures refer to IEC 60060-1.		

Page 16

8.3.5 Switching impulse sparkover-voltage/time curve test

Replace the second sentence in the subclause by the following new text:

There are limits only for heavy-duty arresters with rated voltages above 200 kV. For these arresters the limits are given in table 8 (column 7).

Page 25

8.7 Pressure-relief tests

Replace the existing title and text of this clause by the following:

8.7 Short-circuit tests

8.7.1 General

Arresters, for which a short-circuit withstand is claimed by the manufacturer, shall be tested in accordance with this subclause. The test is made to show that an arrester failure is not likely to cause an explosive failure. Each arrester type is tested at three different values of short-circuit currents; the rated short-circuit current and two reduced short-circuit currents. Another test is used to verify the capability of the pressure-relief device or of the surge arrester withstanding, for a low magnitude fault current. If the arrester is equipped with some other arrangement, as a substitute for a conventional pressure-relief device, this arrangement shall be included in the test.

The frequency of the short-circuit test current supply shall be no less than 48 Hz and no more than 62 Hz.

In addition, some re-closing cycles can be performed after agreement between the manufacturer and the purchaser. For this special test, the procedure and the acceptance criteria shall be agreed between the manufacturer and the purchaser.

8.7.2 Preparation of the test samples

For the high-current tests the test samples shall be the longest arrester unit, with the highest rated voltage of each different design of arrester. For the low current test the test sample may be an arrester unit of any length of each different design. The test sample shall be of the highest rated voltage used for the tested length. The samples shall be prepared with a fuse wire for conducting the required short-circuit current.

The external fuse wire shall be placed along the surface of the active part (non-linear resistor and gaps) inside the arrester housing, such that the entire active part is short-circuited. If the space between the active part and the arrester housing is filled with a combination of solid material and a channel of gas or liquid, the fuse wire shall be located as far as possible from this gas or liquid channel. Figure 2 shows some examples of such cases. The actual location of the fuse wire in the test shall be reported.

The fuse wire material and size shall be selected so that the wire will melt within the first 30 electrical degrees after the initiation of the test current.

According to table 9 a total of four test samples is required for the rated short-circuit current test, one for the high-current test, one for each of the two reduced short-circuit current tests and one for the low current test.

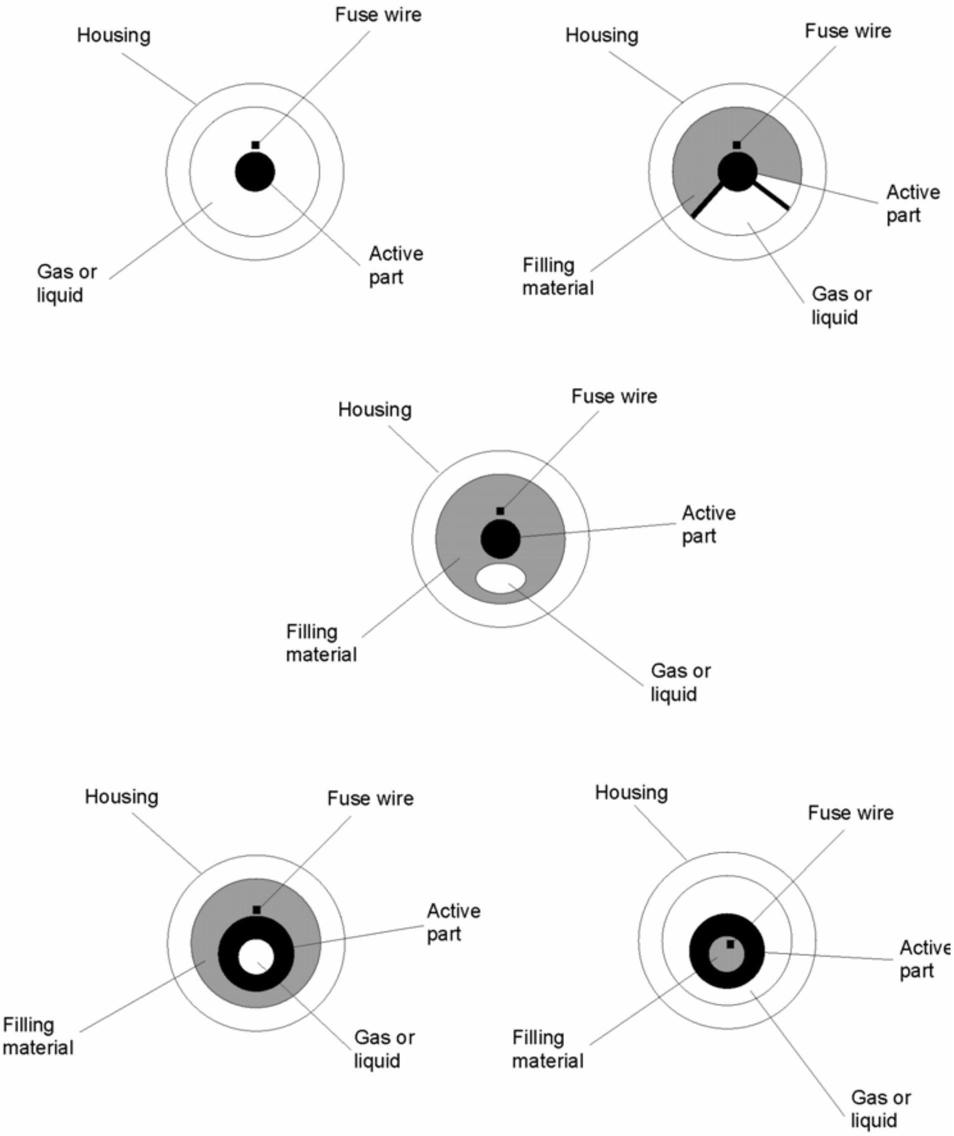

Figure 2 – Position of the fuse wire in different cases

Table 9 – Required currents for short-circuit tests

Arrester class = nominal discharge current A	**Rated short-circuit current** A	**Reduced short-circuit currents** A		**Low short-circuit current with a duration of 1 s*** A
20 000 or 10 000	80 000	50 000	25 000	600 ± 200
20 000 or 10 000	63 000	25 000	12 000	600 ± 200
20 000 or 10 000	50 000	25 000	12 000	600 ± 200
20 000 or 10 000	40 000	25 000	12 000	600 ± 200
20 000 or 10 000	31 500	12 000	6 000	600 ± 200
20 000, 10 000 or 5 000	20 000	12 000	6 000	600 ± 200
10 000 or 5 000	16 000	6 000	3 000	600 ± 200
10 000, 5 000, 2 500 or 1 500	10 000	6 000	3 000	600 ± 200
10 000, 5 000, 2 500 or 1 500	5 000	3 000	1 500	600 ± 200

* For surge arresters to be installed in resonant earthed or unearthed neutral systems, the increase of the test duration to longer than 1 s, up to 30 min, may be permitted after agreement between the manufacturer and the purchaser. Then the low short-circuit current shall be reduced to 50 A ± 20 A. For this special test, the test sample and acceptance criteria shall be agreed between the manufacturer and the purchaser.

NOTE 1 If an existing type of an arrester, already qualified for one of the nominal currents in table 9, is being qualified for a higher nominal current value than available in this table, it shall be tested only at the new nominal value. Any extrapolation can only be extended by two steps of rated short-circuit current.

NOTE 2 If a new arrester type is to be qualified for a higher nominal current value than available in this table it shall be tested at the proposed nominal current, at 50 % and at 25 % of this nominal current.

NOTE 3 If an existing arrester is qualified for one of the rated short-circuit currents in this table, it is deemed to have passed the test for any value of rated current lower than this one.

8.7.3 Mounting of the test sample

Test samples shall be mounted to simulate installation conditions. For a base-mounted arrester, a mounting arrangement is shown in figures 3a and 3b. The distance to the ground of the insulating platform and the conductors shall be as indicated in figures 3a and 3b.

For non-base mounted arresters (e.g. pole mounted arresters), the test sample shall be mounted to a non-metallic pole using mounting brackets and hardware typically used for service installation. For the purpose of this test, the mounting bracket shall be considered as a part of the arrester base. In cases where the foregoing is in variance with the manufacturer's instructions, the arrester shall be mounted in accordance with the installation recommendations of the manufacturer. The entire lead between the base and the current sensor shall be insulated for at least 1 000 V. The top end of the test sample shall be fitted with the base assembly of the same design as that of an arrester or with the top cap.

For base-mounted arresters, the bottom end fitting of the test sample shall be mounted on an insulating support that is the same height as a surrounding circular or square enclosure. The insulating support and the enclosure shall be placed on top of an insulating platform, as shown in figures 3a and 3b. For non-base mounted arresters, the same requirements apply to the bottom of the arrester. The arcing distance between the top end cap and any other metallic object (floating or grounded), except for the base of the arrester, shall be at least 1,6 times the height of the sample arrester, but not less than 0,9 m. The enclosure shall be made of non-metallic material and be positioned symmetrically with respect to the axis of the test sample. The height of the enclosure shall be 40 cm ± 10 cm, and its diameter (or side, in case of a square enclosure) shall be equal to the greater of 1,8 m or the diameter of the test sample plus twice the test sample height. The enclosure shall not be permitted to open or move during the test.

For practical reasons an alternative enclosure is a square enclosure made of wood for example, having a side equal to the diameter of the circular enclosure.

Test samples shall be mounted vertically, unless otherwise agreed upon between the manufacturer and the purchaser.

NOTE The mounting of the arrester during the short-circuit test and, more specifically, the routing of the conductors must represent the most unfavourable condition in the field. The routing shown in figure 3a is the most unfavourable to use during the initial phase of the test before venting occurs (especially in the case of a surge arrester fitted with a pressure-relief device).

However, during the remaining arcing time, this routing forces the arc to move away from the arrester, thus reducing the risk of the arrester catching fire. For arresters without a pressure-relief device, it is proposed that, as an alternative, the direction of the venting ports (if any) remains as in figure 3a, but the ground conductor should be directed to the right, as described in figure 3b. In this way, the arc will stay close to the arrester during the entire duration of the short-circuit current, thus creating the most unfavourable conditions with regard to the fire hazard.

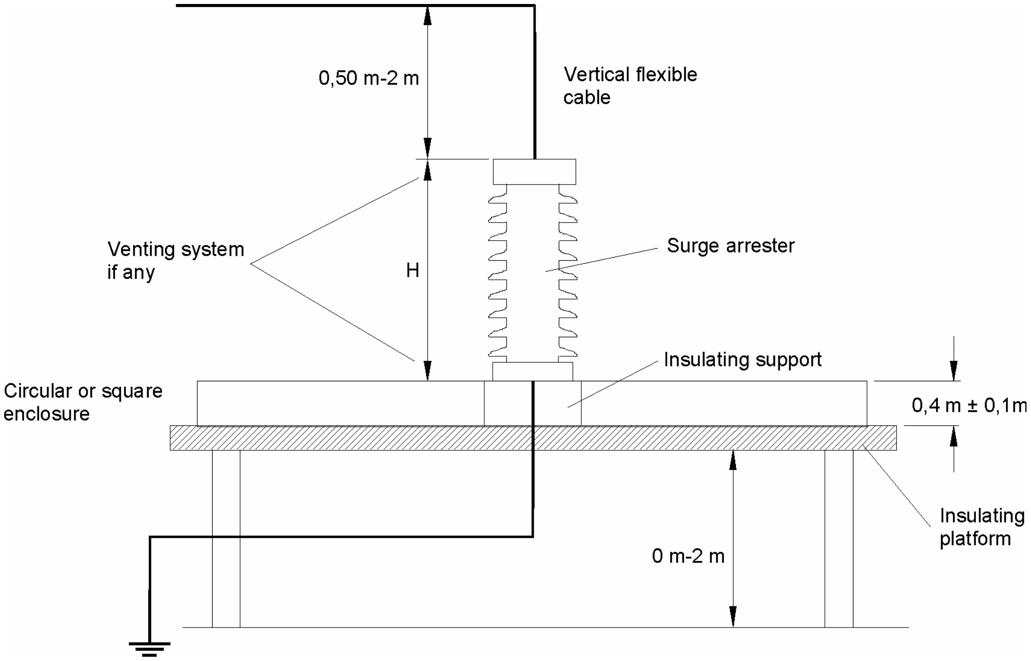

Figure 3a – Circuit layout for surge arresters with a pressure-relief device

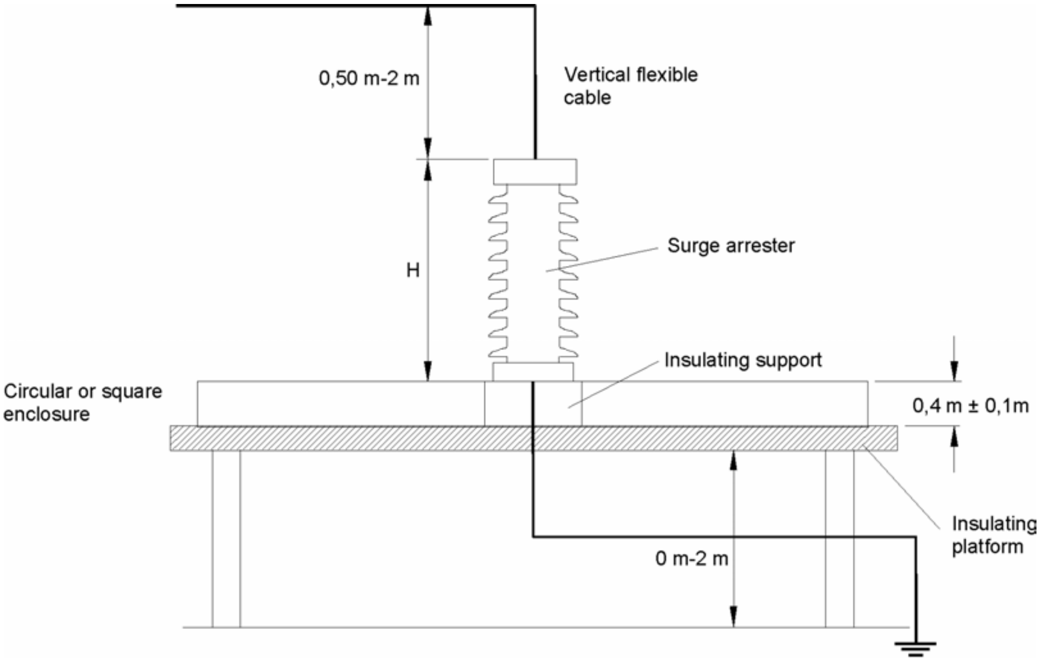

Figure 3b – Circuit layout for surge arresters without a pressure-relief device

Figure 3 – Short-circuit tests

8.7.4 Evaluation of test results

Structural failure of the sample is permitted as long as there is no violent shattering ; except as permitted below, no fragment of the test sample shall fall outside the enclosure.

- The following types of fragments are accepted to fall out of the enclosure:
  - fragments, less than 10 g each, of ceramic material such as non-linear resistors or porcelain;
  - pressure-relief vents, covers and diaphragms consisting of thin and lightweight pieces of metal or plastic.
- During the test the arrester shall be able to self-extinguish open flames within 2 min following the end of the test. Any ejected part (in or out of the enclosure) shall also self-extinguish open flames within 2 min or a shorter duration based on agreement between the purchaser and the manufacturer.

For arresters to be used in applications where mechanical integrity and a strength is required after failure, different test procedures and evaluations may be established between the manufacturer and the user (as an example, it may be required that after the tests the arrester shall still be able to be lifted and removed by its top end).

NOTE 1 Positioning the sample as shown in figure 3a, with the vent ports facing the direction of the test source, may cause the external arc, which is created during the venting operation, to form and be swept in close proximity to the arrester housing. As a result, the thermal shock effect may cause excessive chipping and shattering of the weather sheds, as compared to the other possible orientations of the venting ports.

NOTE 2 If the arrester has not visibly vented at the end of the test, caution should be exercised, as the housing may remain pressurised after the test. This note is applicable to all levels of test current, but is of particular relevance to the low-current pressure-relief tests.

8.7.5 High current short-circuit tests

One sample shall be tested at a rated short-circuit current selected from table 9. A second and third sample shall be tested, respectively, at the higher and lower reduced short-circuit currents corresponding to the selected rated current. All three samples shall be prepared according to 8.7.2 and mounted according to 8.7.3.

Tests shall be made in a single phase test circuit, with an open circuit test voltage of 107 % to 77 % of the rated voltage of the test sample arrester, as outlined in 8.7.5.1. However, it is expected that tests on high voltage arresters will have to be made at a testing station which might not have the sufficient short-circuit power capability to carry out these tests at 77 % or more of the test sample rated voltage. Accordingly, an alternate procedure for making the high current short-circuit tests at a reduced voltage is given in 8.7.5.2. The measured total duration of test current flowing through the circuit, as detected by the current sensor whose installation is described in 8.7.1, shall be equal to or greater than 0,2 s.

NOTE Experience has shown that tests at the rated current do not necessarily demonstrate acceptable behaviour at lower currents.

8.7.5.1 High current tests at full voltage (107 % to 77 % of rating)

The prospective current shall first be measured by making a test with the arrester shorted or replaced by a solid link of negligible impedance.

The duration of such a test may be limited to the minimum time required to measure the peak and symmetrical components of prospective current waveform.

For the rated short-circuit current, the peak value of the first half-cycle of the prospective current shall be at least 2,5 times the r.m.s. value of the symmetrical component of the prospective current. The following r.m.s. value of the symmetrical component shall be equal to the rated short-circuit current or higher. The actual r.m.s. value of the prospective current shall be quoted as the test current for the arrester. For the reduced short-circuit currents the r.m.s. value shall be ±10 % of the required current levels according to table 9. There is no asymmetrical requirement on the first peak.

The X/R ratio of the test circuit impedance, without the arrester connected, shall preferably be at least 15. In cases where the test circuit impedance X/R ratio is less than 15, the test voltage may be increased, or the impedance may be reduced, such that:

- for the rated short-circuit current, the peak value of the first half-cycle of the prospective current is equal to or greater than 2,5 times the required test current level;
- for the reduced current level tests, the tolerances above are met.

The actual peak value of the prospective current, divided by 2,5, shall be quoted as the test current, even though the r.m.s. value of the symmetrical component of the prospective current may be higher. Because of the higher prospective current, the sample arrester may be subjected to more severe duty, and therefore, tests at X/R ratio lower than 15 shall only be carried out with the manufacturer's consent.

The solid shorting link shall then be removed and the arrester sample(s) shall be tested with the same circuit parameters.

NOTE The resistance of the restricted arc inside the arrester may reduce the r.m.s. symmetrical component and the peak value of the measured current. This does not invalidate the test, since the test is made with at least normal service voltage and the effect on the test current is the same as would be experienced during a fault in service.

8.7.5.2 High current test at less than 77 % of rated voltage

When tests are made with a test circuit voltage less than 77 % of the rated voltage of the test samples, the test circuit parameters shall be adjusted such that the r.m.s. value of the symmetrical component of the actual arrester test current shall equal or exceed the required test current level of 8.7.5. For the rated short-circuit current, the peak value of the actual arrester test current in the first half-cycle shall be at least 2,5 times the required test current level. For the reduced short-circuit currents the r.m.s. value shall be ±10 % of the required current levels according to table 9. There is no asymmetrical requirement on the first peak.

The X/R ratio of the test circuit impedance, without the arrester connected, shall preferably be at least 15. In cases where the test circuit impedance X/R ratio is less than 15, the test voltage may be increased or the impedance may be reduced such that, for the rated short circuit current, the peak value of the first half-cycle of the prospective current is equal to or greater than 2,5 times the required test current level.

The actual peak value of the test current, divided by 2,5, shall be quoted as the test current, even though the r.m.s. value of the symmetrical component of the test current may be higher. Because of the higher test current, the sample arrester may be subjected to more severe duty, and therefore, tests at X/R ratio lower than 15 shall only be carried out with the manufacturer’s consent.

NOTE If the circuit that produces the required asymmetrical current results in higher symmetrical value than required, current may be reduced, not less than 2,5 cycles after initiation, to the required symmetrical value.

8.7.6 Low current short-circuit test

The test shall be made with any test circuit that will produce a current through the test sample arrester of 600 A ± 200 A r.m.s., measured at approximately 0,1 s after the start of the current flow. The current shall flow for 1 s. In the case of a surge arrester fitted with a pressure-relief device, the arrester design shall be considered to have failed this test if venting does not occur during the test.

Refer to note 2 of 8.7.4 with regard to handling an arrester that fails to vent.

(ETD 30)

Reprography Unit, BIS, New Delhi, India

Indian Standard
SURGE ARRESTERS
PART 1 NON-LINEAR RESISTOR TYPE GAPPED SURGE ARRESTERS FOR a.c. SYSTEMS

SECTION 1: GENERAL

1.1 Scope

This part of International Standard IEC 99 applies to surge protective devices designed for repeated operation to limit voltage surges on a.c. power circuits and to interrupt power-follow current. In particular, it applies to surge arresters consisting of single or multiple spark gaps in series with one or more non-linear resistors.

1.2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this part of International Standard IEC 99. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this part are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

IEC 60: *High-voltage test techniques.*

IEC 71-2: 1976, *Insulation co-ordination - Part 2: Application guide.*

IEC 99-3: 1990, *Surge arresters - Part 3: Artificial pollution testing of surge arresters.*

SECTION 2: DEFINITIONS

For the purpose of this part, the following definitions apply:

2.1 **surge arrester***: A device designed to protect electrical apparatus from high transient voltage and to limit the duration and frequently the amplitude of follow-current. The term "surge arrester" includes any external series gap which is essential for the proper functioning of the device as installed for service, regardless of whether or not it is supplied as an integral part of the device.

NOTE - Surge arresters are usually connected between the electrical conductors of a network and earth although they may sometimes be connected across the windings of apparatus or between electrical conductors.

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* This type of equipment may be called "surge diverter" in some countries.

2.2 **non-linear resistor type gapped arrester:** An arrester having a single or a multiple spark-gap connected in series with one or more non-linear resistors.

2.3 **series gap of an arrester:** An intentional gap or gaps between spaced electrodes in series with the non-linear series resistor or resistors of the arrester.

2.4 **non-linear series resistor of an arrester:** The part of the surge arrester which, by its non-linear voltage-current characteristics, acts as a low resistance to the flow of high discharge currents thus limiting the voltage across the arrester terminals, and as a high resistance at normal power-frequency voltage thus limiting the magnitude of follow-current.

2.5 **section of an arrester:** A complete, suitably housed part of an arrester including series gaps and non-linear series resistors in such a proportion as is necessary to represent the behaviour of a complete arrester with respect to a particular test.

2.6 **unit of an arrester:** A completely housed part of an arrester which may be connected in series with other units to construct an arrester of higher voltage rating. A unit of an arrester is not necessarily a section of an arrester.

2.7 **pressure-relief device of an arrester:** A means for relieving internal pressure in an arrester and preventing explosive shattering of the housing following prolonged passage of follow-current or internal flashover of the arrester.

2.8 **rated voltage of an arrester:** The designated maximum permissible r.m.s. value of power-frequency voltage between its terminals at which it is designated to operate correctly. This voltage may be applied to the arrester continuously without changing its operating characteristics.

2.9 **rated frequency of an arrester:** The frequency of the power system on which the arrester is designed to be used.

2.10 **disruptive discharge:** The phenomena associated with the failure of insulation under electrical stress which include a collapse of voltage and the passage of current; the term applies to electrical breakdown in solid, liquid and gaseous dielectrics and combinations of these.

NOTE - A disruptive discharge in a solid dielectric produces permanent loss of electrical strength; in a liquid or gaseous dielectric the loss may be only temporary.

2.11 **puncture:** A disruptive discharge through a solid.

2.12 **flashover:** A disruptive discharge over a solid surface.

2.13 **sparkover of an arrester:** A disruptive discharge between the electrodes of the gaps of an arrester.

2.14 **impulse:** A unidirectional wave of voltage or current which, without appreciable oscillations, rises rapidly to a maximum value and falls, usually less rapidly, to zero with small, if any, loops of opposite polarity.

The parameters which define a voltage or current impulse are polarity, peak value, front time, and time to half value on the tail.

2.15 **rectangular impulse:** An impulse which rises rapidly to a maximum value, remains substantially constant for a specified period, and then falls rapidly to zero.

The parameters which define a rectangular impulse are polarity, peak value, virtual duration of the peak, and virtual total duration.

2.16 **peak (crest) value of an impulse:** The maximum value of voltage or current in an impulse. In case of superimposed oscillations see 8.3.2, 8.5.2 e), and 8.5.3.2 c).

2.17 **front of an impulse:** That part of an impulse which occurs prior to the peak.

2.18 **tail of an impulse:** That part of an impulse which occurs after the peak.

2.19 **full-wave voltage impulse:** A voltage impulse which is not interrupted by sparkover, flashover, or puncture.

2.20 **chopped voltage impulse:** A voltage impulse which is interrupted on the front, peak, or tail by sparkover, flashover or puncture causing a sudden drop in the voltage.

2.21 **prospective peak (crest) value of a chopped voltage impulse:** The peak (crest) value of the full-wave voltage impulse from which a chopped voltage impulse is derived.

2.22 **virtual origin of an impulse:** The point on a graph of voltage versus time or current versus time determined by the intersection between the time axis at zero voltage or zero current and a straight line drawn through two reference points on the front of the impulse.

a) For voltage impulses with virtual front times equal to or less than 30 µs, the reference points are at 30 % and 90 % of the peak value.

b) For voltage impulses with virtual front times greater than 30 µs, the origin is generally well defined and needs no artificial definition.

c) For current impulses, the reference points are 10 % and 90 % of the peak value.

NOTE - This definition applies only when scales of both ordinate and abscissa are linear. See also note to 2.23.

2.23 **virtual front time of an impulse (T_1):** The time, in microseconds, equal to:

a) for voltage impulses with front durations equal to or less than 30 µs, 1,67 times the time taken by the voltage to increase from 30 % to 90 % of its peak value;

b) for voltage impulses with front durations greater than 30 µs, 1,05 times the time taken by the voltage to increase from 0 % to 95 % of its peak value;

c) for current impulses, 1,25 times the time taken by the current to increase from 10 % to 90 % of its peak value.

NOTE - If oscillations are present on the front, the reference points at 10 %, 30 %, 90 % and 95 % should be taken on the mean curve drawn through the oscillations.

2.24 **virtual steepness of the front of an impulse:** The quotient of the peak value and the virtual front time of an impulse.

2.25 **virtual time to half value on the tail of an impulse (T_2):** The time interval between the virtual origin and the instant when the voltage or current has decreased to half its peak value. This time is expressed in microseconds.

2.26 **designation of an impulse shape:** A combination of two numbers, the first representing the virtual front time (T_1) and the second the virtual time to half value of the tail (T_2). It is written as T_1/T_2, both in microseconds, the sign "/" having no mathematical meaning.

2.27 **standard lightning voltage impulse:** An impulse voltage having a waveshape designation of 1,2/50.

2.28 **switching voltage impulse:** An impulse having a virtual front time greater than 30 µs.

2.29 **virtual duration of the peak of a rectangular impulse:** The time during which the amplitude of the impulse is greater than 90 % of its peak value.

2.30 **virtual total duration of a rectangular impulse:** The time during which the amplitude of the impulse is greater than 10 % of its peak value. If small oscillations are present on the front, a mean curve should be drawn in order to determine the time at which the 10 % value is reached.

2.31 **peak (crest) value of opposite polarity of an impulse:** The maximum amplitude of opposite polarity reached by a voltage or current impulse when it oscillates about zero before attaining a permanent zero value.

2.32 **discharge current of an arrester:** The surge or impulse current which flows through the arrester after a sparkover of the series gaps.

2.33 **nominal discharge current of an arrester:** The peak value of discharge current, having an 8/20 waveshape, which is used to classify an arrester. It is also the discharge current which is used to initiate follow-current in the operating duty test.

2.34 **follow-current of an arrester:** The current from the connected power source which flows through an arrester following the passage of discharge current.

2.35 **residual voltage (discharge voltage) of an arrester:** The voltage that appears between the terminals of an arrester during the passage of discharge current.

2.36 **power-frequency sparkover voltage of an arrester:** The value of the power-frequency voltage measured as the peak value divided by $\sqrt{2}$ applied between the terminals of an arrester, which causes sparkover of all the series gaps.

2.37 **impulse sparkover voltage of an arrester:** The highest value of voltage attained before sparkover during an impulse of given waveshape and polarity applied between the terminals of an arrester.

2.38 **front-of-wave impulse sparkover of an arrester:** The impulse sparkover voltage obtained on the wavefront the voltage of which increases linearly with time.

2.39 **standard lightning impulse sparkover voltage of an arrester:** The lowest prospective peak value of a standard lightning voltage impulse which, when applied to an arrester, causes sparkover on every application.

2.40 **time to sparkover of an arrester:** The time interval between virtual origin and the instant of sparkover of the arrester. The time is expressed in microseconds.

2.41 **impulse sparkover-voltage/time curve:** A curve which relates the impulse sparkover voltage to the time to sparkover.

2.42 **prospective current:** The current which would flow at a given location in a circuit if it were short-circuited at that location by a link of negligible impedance.

2.43 **type tests (design tests):** Tests which are made upon the completion of the development of a new arrester design to establish representative performance and to demonstrate compliance with this part of the standard. Once made, these tests need not be repeated unless the design is so changed as to modify its performance.

2.44 **routine tests:** Tests made on each arrester or on parts and materials as required to ensure that the product meets the design specifications.

2.45 **acceptance tests:** Selected tests which are made when it has been agreed between the manufacturer and the purchaser that the arresters or representative samples of an order are to be tested.

2.46 **protective characteristics of an arrester:** The combination of the following:

a) lightning impulse sparkover-voltage/time curve as determined in 8.3.3;

b) the residual-voltage/discharge-current curve as determined in clause 8.4;

c) for 10 000 A arresters rated 100 kV and higher, the switching-voltage impulse sparkover-voltage/time curve as determined in 8.3.5.

2.47 **arrester disconnector:** A device for disconnecting an arrester from the system in the event of arrester failure to prevent a persistent fault on the system and to give visible indication of the failed arrester.

NOTE - Clearing of the fault current through the arrester during disconnection generally is not a function of the device, and it may not prevent explosive shattering of the housing following internal flashover of the arrester on high fault currents.

SECTION 3: IDENTIFICATION AND CLASSIFICATION

3.1 Arrester identification

Surge arresters shall be identified by the following minimum information which shall appear on the rating plate (nameplate):

- rated voltage;
- rated frequency, if other than one of the standard frequencies, see 4.2;
- nominal discharge current (specifying for the 5 000 A arrester whether series A or series B*, and for the 10 000 A arrester, whether light or heavy duty);
- long-duration discharge class (for 10 000 A heavy-duty arresters), see 8.5.3.2;
- pressure-relief class (for arresters fitted with pressure-relief devices), see 8.7.2;
- manufacturer's name or trademark, type and identification;
- year of manufacture.

NOTES

1 Information to be given by inquiry or tender may be guided by annex B.

2 In some countries, it is customary to classify arresters as:
- station for 10 000 A arresters;
- intermediate (series A) or distribution (series B) for 5 000 A arresters*;
- secondary for 1 500 A arresters.

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* Series A arresters are based on performance characteristics in practice in all countries. Series B arresters are based on performace characteristics in Canada and the United States of America and other countries.

3.2 Arrester classification

Surge arresters are classified by their standard nominal discharge currents and they shall meet at least the test requirements and performance characteristics listed in table 3. Arresters having more favorable performance characteristics or lower protective levels than those required in this part shall be considered to have met this standard.

SECTION 4: STANDARD RATINGS

4.1 Standard voltage ratings

Standard values of rated voltages for arresters shall be as listed in Table 1.

Table 1 - Standard voltage ratings (kV r.m.s.)

0,175	6	18	36	75	126
0,280	7,5	21	39	84	138
0,500	9	24	42	96	150
0,660	10,5	27	51	102	174
3	12	30	54	108	186
4,5	15	33	60	120	198

For voltage ratings above 198 kV, the arrester ratings shall be divisible by 6.

4.2 Standard rated frequencies

The standard rated frequencies are 50 Hz and 60 Hz.

4.3 Standard nominal discharge currents

The standard nominal discharge currents are: 10 000 A, 5 000 A, 2 500 A and 1 500 A, having an 8/20 waveshape.

NOTE - For the 10 000 A arrester (see 3.2) there are two types, light-duty and heavy-duty, which are differentiated by the amplitude of the long-duration impulse current which they are capable of withstanding. See 8.5.3.

4.4 Service conditions

4.4.1 *Normal service conditions*

Surge arresters which conform to this part of the standard shall be suitable for operation under the following normal service conditions:

a) ambient temperature within the range of –40 °C to +40 °C;

b) altitude not exceeding 1 000 m;

c) frequency of the a.c. power supply not less than 48 Hz and not exceeding 62 Hz;

d) power-frequency voltage applied between the line and earth terminals of the arrester not exceeding its rated voltage.

4.4.2 *Abnormal service conditions*

Arresters subjected to other than normal application or service conditions may require special consideration in manufacture or application and each case should be discussed with the manufacturer. See annex A: Abnormal service conditions and annex C: Selection of the long-duration discharge class of heavy-duty arresters.

SECTION 5: REQUIREMENTS

5.1 Power-frequency sparkover voltage

For all classes of surge arresters, except the 10 000 A heavy-duty class, the lowest value of power-frequency sparkover voltage shall be not less than 1,5 times the rated voltage of the arrester. For the 10 000 A heavy-duty class arresters, the lowest value of power-frequency sparkover is subject to agreement between the manufacturer and the purchaser.

It should be noted that the dry power-frequency sparkover test is the minimum requirement for routine tests to be made by the manufacturer as specified in 6.1.

5.2 Standard lightning impulse sparkover voltage

With the lightning impulse voltage specified in 8.3.2 and table 8 the arrester shall sparkover on every impulse of a series of five positive and five negative impulses.

If in either series of five impulses, the gaps fail to sparkover once only, an additional ten impulses of that polarity shall be applied and the gaps shall sparkover on all of these impulses.

5.3 Front-of-wave impulse sparkover voltage

With voltage impulses having a virtual steepness of front equal to that specified in table 8, the sparkover voltage shall not exceed the value given in table 8. This is verified according to 8.3.4 by a test with five positive and five negative impulses, or by using the lightning impulse sparkover voltage/time curve described in 8.3.3.

5.4 Switching impulse sparkover voltage

This voltage is determined on 10 000 A arresters having a rated voltage above 100 kV according to 8.3.5. No limits for the maximum switching impulse sparkover voltage have been specified.

5.5 Lightning impulse residual voltage

The residual voltage for nominal discharge current is determined from the curve drawn according to 8.4.1. This voltage shall not be higher than the maximum residual voltage of the arrester specified in table 8.

5.6 Switching impulse residual voltage

This requirement applies to 10 000 A, light or heavy duty, or 5 000 A series A arresters, having a rated voltage above 100 kV and with active gaps (an active gap is defined as a gap which generates at least 100 V/kV of rating during the switching impulse test).

The switching impulse residual voltage determined according to 8.4.2 shall not exceed the value indicated in table 8.

5.7 High-current impulse withstand

Arresters shall withstand the high-current impulse test according to 8.5.2. The average dry power-frequency sparkover voltage (see 8.2) recorded before and after this test shall not have changed by more than 10 %. Examination of the test samples shall reveal no evidence of puncture or flashover of the non-linear resistors or significant damage to the series gaps or grading circuit.

5.8 Long-duration current withstand

Arresters shall withstand the long-duration current impulse test according to 8.5.3 and tables 5 (heavy-duty) or 6 (light-duty). The average dry power-frequency sparkover voltage of 8.2 recorded before and after this test shall not have changed by more than 10 %.

5.9 Operating-duty

Arresters shall withstand the operating-duty test described in 8.6 during which:

- follow-current shall be established by each test impulse and the test sample shall interrupt the follow-current each time;
- final interruption of the follow-current shall occur at least at the end of the half-cycle following that in which the impulse is applied.

Following the operating-duty test and after the test sample has cooled to near ambient temperature, the power-frequency sparkover test and the residual voltage test which were made before the operating-duty test are repeated and the average values shall not have changed by more than 10 %.

5.10 Pressure-relief

When an arrester is fitted with a pressure-relief device, the failure of the arrester shall not cause explosive shattering of the housing. This is verified by the tests described in 8.7.

The test sample is deemed to have passed the test if the housing remains intact or if it breaks sufficiently non-explosively and if all parts of the sample are contained within the circular enclosure.

5.11 Disconnectors

5.11.1 *Disconnector withstand*

When an arrester is fitted or associated with a disconnector, this device shall withstand, without operating, each of the following tests:

- high-current impulse test (8.8.2.1);
- long-duration current impulse test (8.8.2.2);
- operating-duty test (8.8.2.3).

5.11.2 *Disconnector operation*

The time delay for the operation of the disconnector is determined for three values of current: 20 A, 200 A and 800 A r.m.s., ± 10 % according to 8.8.3. There shall be clear evidence of effective and permanent disconnection by the device.

SECTION 6: GENERAL TESTING PROCEDURE

6.1 Test samples and measurements

Except when specified otherwise, all tests shall be made on the same arresters, arrester sections or arrester units. They shall be new, clean, completely assembled, and arranged as nearly as possible as in service and shall be fitted with grading rings, if used.

The measuring equipment shall meet the requirements of IEC 60, and the values obtained shall be accepted as accurate for the purpose of compliance with the relevant test clauses.

6.2 Power-frequency voltage tests

All power-frequency tests shall be made with an alternating voltage having a frequency between the limits of 48 Hz and 62 Hz, and an approximately sinusoïdal waveshape.

6.3 Wet tests

This clause is in agreement with the recommendations on wet tests contained in IEC 60. It is generally recognized that wet tests are not intended to reproduce actual operating conditions but to provide a criterion based on accumulated experience that satisfactory service operation will be obtained.

The test shall give reproducible results in the same and in different laboratories.

The tests shall be made only on arresters designed for use outdoors. Where such a test is specified, the test object shall be subjected to a spray of water of prescribed resistivity provided by a properly located nozzle or nozzles. The spray, consisting of small drops, shall fall on the test object at an angle approximately 45° to the vertical as determined by visual observation or by measurements of the vertical and horizontal components of the precipitation rate.

The vertical component of the spray shall be measured with a collecting vessel having a horizontal opening of area 100 cm^2 to 750 cm^2. When both vertical and horizontal components are required, the horizontal component will be measured with a collecting vessel having a similar vertical opening directed towards the nozzles. The collecting vessel shall be located on the side of the test object facing the nozzles and as close to the test object as is possible without collecting splashes from it.

For test objects of height greater than 50 cm, measurements of the rate of precipitation shall be made near the ends and the middle and values obtained for any one position shall not differ by more than 25 % from the average for the three positions; for test objects of 50 cm height or less, the measurement shall be made near the middle only.

The test object shall be sprayed for at least 1 min before the application of voltage. (Alternatively, more consistent results may be obtained if the test object is thoroughly wetted with water of the prescribed resistivity and temperature before the application of voltage.) The characteristics of the spray shall be as given in table 2. Two sets are given, one in general accordance with European practice, the other with practice in Canada and in the United States of America. It is recommended that each National Committee use only one of these practices.

Table 2 - Parameters for wet tests

Characteristics	Practice	
	Europe	Canada and United States of America
1. Precipitation rate (vertical component)	3 mm/min ±10 %	5 mm/min ±10 %
2. Resistivity of water	10 000 Ω • cm ±10 %	17 800 Ω • cm ±10 %
3. Temperature of water	Ambient temperature ±15 °C	Ambient temperature ±15 °C
4. Type of nozzle	See figure 1*	See figure 2*
5. Water pressure	See figure 1*	See figure 2*
* Figure numbers refer to IEC 60 (1962).		

6.4 Artificial-pollution tests

Artificial-pollution tests are described in IEC 99-3. This report gives the basic principles of artificial-pollution testing of non-linear resistor type gapped surge arresters, together with details of pollutant compositions and methods of application and the test procedures associated with each mode of pollution.

SECTION 7: ROUTINE AND ACCEPTANCE TESTS

7.1 Routine tests

The minimum requirement for routine tests to be made by the manufacturer shall be the dry power-frequency sparkover test, (see 8.2). If the arrester is constructed with a number of self-contained units, the tests may be made on the units.

7.2 Acceptance tests

When the purchaser specifies acceptance tests in the purchase agreement, the following tests shall be made on the nearest highest whole number to the cube root of the number of arresters to be supplied:

a) dry power-frequency voltage sparkover test on the complete arrester (see 8.2);

b) standard lightning impulse sparkover test on the complete arrester (see 8.3.2);

c) only when specifically agreed between the manufacturer and the purchaser, residual voltage shall be determined at a discharge current of not less than 0,25 times the nominal discharge current on the complete arrester or on each of the individual units of the arrester or sections (see 8.4). When the tests are made on sections, the tests shall apply to all types of elements of the arrester, and the elements of the tested sections shall be distinct.

Any alteration in the number of samples or type of tests shall be specifically negotiated between the manufacturer and the purchaser.

SECTION 8: TYPE TESTS (DESIGN TESTS)

8.1 General

The following type tests shall be made as far as required in table 3:

1) Measurement of power-frequency sparkover voltage (8.2).
2) Standard lightning impulse sparkover test (8.3.2).
3) Lightning impulse sparkover-voltage/time curve test (8.3.3).
4) Measurement of front-of-wave impulse sparkover-voltage (8.3.4).
5) Switching impulse sparkover-voltage/time curve test (8.3.5).
6) Measurement of residual voltages (8.4).
7) Current impulse withstand tests (8.5).
8) Operating-duty test (8.6).
9) Pressure-relief tests (when the arrester is fitted with a pressure-relief device) (8.7).
10) Tests of arrester disconnectors (8.8).

Table 3 - Arrester classification and test requirements

	Standard nominal discharge current A					
	10 000 Heavy-duty	10 000 Light-duty	5 000			
			Series A	Series B	2 500	1 500
1. Voltage ratings (kV r.m.s.)	3 or more	3 or more	3 to 138	3 to 39	Up to 36	Up to 0,660
2. Power-frequency voltage sparkover test	8.2	8.2	8.2	8.2	8.2	8.2
3. Standard lightning-voltage impulse sparkover test	8.3.2, table 8, column 2	8.3.2, table 8, column 3	8.3.2, table 8, column 3	8.3.2, table 8, column 3	8.3.2, table 8, column 3	Not required
4. Front-of-wave-voltage sparkover test	8.3.4	8.3.4	8.3.4	8.3.4	8.3.4	8.3.4
5. Switching impulse sparkover-voltage/time curve test	8.3.5 (above 100 kV)	8.3.5 (above 100 kV)	Not required	Not required	Not required	Not required
6. Residual voltage test	8.4, table 8, column 8	8.4, table 8, column 9	8.4, table 8, column 9	8.4, table 8, column 9	8.4, table 8, column 9	8.4
7. Current impulse withstand:						
a) High-current	8.5.2	8.5.2	8.5.2	8.5.2	8.5.2	8.5.2
b) Long-duration	8.5.3.2	8.5.3.3	8.5.3.3	8.5.3.3	8.5.3.3	Not required
8. Operating-duty test	8.6	8.6	8.6	8.6	8.6	8.6
9. Pressure-relief test (when fitted with relief device)	8.7	8.7	8.7	Not appropriate	Not required	Not required
10. Arrester disconnector (when fitted)	Not appropriate	Not appropriate	8.8	8.8	8.8	8.8

The required number of samples is specified in the individual subclauses. Arresters which differ only in methods of mounting or arrangement of the supporting structure, and which are otherwise based on the same components with similar construction and performance characteristics are considered to be of the same design.

Tests 1, 2, 3, 4 and 5 in the foregoing list shall be made on the same samples; these same samples may also be used for test 6 and then shall be considered to have been made on new arresters. For tests 7, 8, 9 and 10 see the recommendations in the specific subclauses.

8.2 Power-frequency voltage sparkover tests

Dry and wet tests shall be made in accordance with 7.1, 7.2, 7.3 and 8.1 on three samples of complete arresters of each voltage rating tested. The performance for other voltage ratings of the same design (as defined in 8.1) within ±25 % (or 6 kV, whichever is greater) of a test sample rating can be determined by adjusting the voltage level in proportion to the voltage ratings. The voltage applied to the arrester shall be switched on at a value low enough to avoid sparkover of the arrester by the resulting switching surge and raised rapidly at a uniform rate until sparkover of the series gap occurs. The time during which the voltage may exceed the rated voltage of the arrester shall be in the range of 2 s to 5 s when testing arresters using grading resistors which may be damaged by overheating if the applied voltage exceeds the rated voltage for too long. After sparkover, the test voltage shall be switched off as rapidly as possible, preferably by automatic tripping and in any case within 0,5 s. If it is difficult to measure the rapidly increasing voltage with an indicating type of instrument, a high speed recorder or an oscillograph shall be used. It is recommended that the manufacturer be consulted about the permissible test procedure.

The load imposed on the testing circuit by a surge arrester having non-linear grading resistors of high conductivity gives rise to harmonics, and the test-circuit must have a sufficiently low impedance to maintain the waveform of the voltage across the specimen within the limits specified in the current edition of IEC 60.

The voltage shall be applied not less than five times, with an interval of about 10 s between successive applications.

The average sparkover value of the five tests is adopted as the power-frequency sparkover voltage for purposes of a comparison of tests made before and after other type tests.

8.3 Voltage impulse sparkover tests

8.3.1 *General*

These tests shall be made in accordance with 7.1 and 8.1 on the same test samples of complete arresters used for the power-frequency sparkover tests described in 8.2. Sparkover values and voltage/time curves for other voltage ratings of the same design as defined in 8.1 within ±25 % (or 6 kV, whichever is greater) of a test sample rating can be determined by adjusting the voltage level in proportion to the voltage ratings.

8.3.2 *Standard lightning impulse sparkover test*

With the test sample arrester in the circuit, the impulse generator is adjusted to give a 1,2/50 voltage waveshape and the peak value specified in table 8. With this adjustment, five positive and five negative impulses shall be applied to the test sample and the series gaps of the arrester shall spark over on every impulse. If in either series of five impulses, the gaps fail to spark over once only, an additional ten impulses of that polarity shall be applied and the gaps must spark over on all of these impulses.

The time interval between the start of the wave and the instant of sparkover is immaterial in this test.

The tolerances on the adjustment of the testing equipment shall be such that the measured values lie within the following limits:

a) between 97 % and 100 % for the specified peak values;

b) *from* 0,85 µs *to* 1,6 µs for the virtual duration of the wavefront;

c) from 40 µs to 60 µs for the time to half value on the wavetail.

Oscillations on the first part of the wavefront (below 50 %) shall not exceed 10 % of the peak value. Small oscillations near the peak of the impulse are permissible provided that their amplitude is less than 5 % of the peak value. Measurement shall be made at the peak of the oscillations.

8.3.3 *Lightning impulse sparkover-voltage/time curve test*

This test shall be made using positive or negative impulses, whichever result in the higher sparkover voltages. Data for plotting the curve are obtained by applying 1,2/50 voltage impulses of successively increasing amplitudes in steps beginning at a voltage below arrester sparkover and increasing the generator charging voltage (and thus the prospective peak voltage) until the virtual steepness of the front of the impulse equals that specified in table 8. Alternatively, for times to sparkover of less than 1,2 µs, the data may be obtained by reducing the virtual front time of the impulse. For times to sparkover of less than 1,2 µs, the test impulse shall have a substantially uniform rate of rise to arrester sparkover.

For each sparkover, the highest voltage attained before sparkover shall be plotted against the time to sparkover measured from virtual origin. Enough data points shall be obtained to define clearly the curve which should be drawn through the maximum sparkover values.

8.3.4 *Front-of-wave impulse sparkover test*

Using a voltage impulse with a virtual steepness of front equal to that specified in table 8, five positive and five negative impulses shall be applied to the arrester and the sparkover voltage is determined from voltage-time oscillograms made during each test. On none of the impulses shall the sparkover voltage exceed the value given in the appropriate column of table 8.

It is permissible to use the point of intersection of the curve specified in 8.3.3 with a line representing the virtual steepness of front specified in table 8 for determining the maximum front-of-wave sparkover voltage of the test sample arrester for comparison with the maximum permissible value given in table 8 provided there are at least five positive and five negative sparkover test points within ±0,1 µs of the line representing the prescribed steepness. This is illustrated in figure 1.

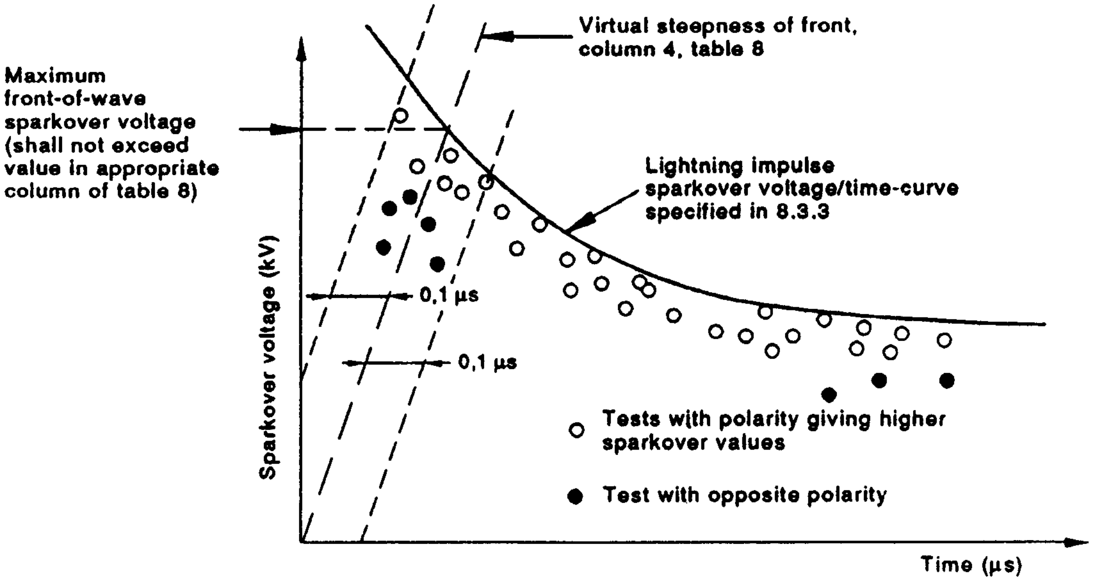

Figure 1 - Front-of-wave voltage sparkover test

8.3.5 *Switching impulse sparkover-voltage/time curve test*

This test is applicable only to 10 000 A light and heavy duty arresters having a rated voltage above 100 kV, and is intended to demonstrate the sparkover characteristics on switching surges. No limits for the maximum switching impulse sparkover voltage are specified. The procedure is prescribed in order to provide a uniform method of making the test so that data supplied by manufacturers will be comparable.

Sparkover tests shall be made using different voltage impulse waveshapes with virtual front times between:

a) 30 µs and 60 µs;

b) 150 µs and 300 µs;

c) 1 000 µs and 2 000 µs.

The time to half value on the tail should be appreciably longer than twice the front time but the exact value is not of critical importance.

For each waveshape and for both polarities, the 50 % sparkover voltage ($U_{50\ \%}$) is first determined by applying an impulse having a peak voltage well below the expected 50 % sparkover voltage of the test sample arrester and raising the impulse generator charging voltage in approximately 5 % steps until sparkover occurs. This sparkover shall constitute the first of five impulses whose highest voltage values are recorded. The remainder of the series of five impulses are applied, decreasing the generator charging voltage (and thus the prospective peak voltage) by about 5 % each time the arrester sparks over, and increasing it by about 5 % each time the arrester does not spark over. $U_{50\ \%}$ is calculated as the average of the highest values of voltage recorded in each of the five tests. Ten more impulses are then applied to the test sample with the impulse generator charging voltage increased so as to give a prospective peak voltage about 40 % higher than $U_{50\ \%}$.

Data for all sparkovers occurring in the test series to establish $U_{50\,\%}$ as well as during the subsequent series at 1,4 ($U_{50\,\%}$) is used in plotting the switching impulse sparkover-voltage/time curve. The highest voltage reached before sparkover is plotted against the time from actual zero to sparkover for each test in which sparkover occurs. The sparkover-voltage/time curve is drawn as a smooth curve through the maximum voltage values recorded for both polarities and blending in with the lightning impulse sparkover-voltage/time curve obtained by the procedure given in 8.3.3. It is recommended that coordinate paper with a vertical linear voltage scale and horizontal logarithmic time scale be used.

8.4 Measurement of residual voltage

The test shall be made in accordance with 7.1 and 8.1 on three samples of complete arresters or arrester sections. The samples may be the same as those used for tests of 8.2 and 8.3 if desired. The voltage rating of the test samples shall be at least 3 kV if the rated voltage of the arrester is not less than this, and need not exceed 12 kV.

When the test is performed on a section of an arrester, the residual voltage of the whole arrester is established as the product of the measured value by the ratio of the rated voltage of the whole arrester to the rated voltage of the section.

8.4.1 *Lightning impulse residual voltage*

An 8/20 current impulse shall be used with limits on the adjustment of the equipment such that the measured values are from 7 µs to 9 µs for the front time and from 18 µs to 22 µs for the time to half value on the tail. At least four current impulses shall be applied to each sample with peak values of approximately 0,25, 0,5, 1 and 2 times the nominal discharge current of the arrester. The time between discharges shall be sufficient to permit the sample to return to approximately ambient temperature.

The maximum envelope of the test points are drawn in a residual-voltage/discharge-current curve. The residual voltage corresponding to the nominal discharge current is read on such a curve. Tests at approximately 0,8, 1,0 and 1,2 times the nominal discharge current provide the best means of evaluating the residual voltage at nominal discharge current. The purpose of the above test level at 0,25 times the nominal current is to accommodate acceptance tests on the complete arrester as provided for in 6.2.

8.4.2 *Switching impulse residual voltage*

The test is made on representative production specimens for each significantly different design of either 10 kA light or heavy duty, or 5 kA series A arresters having a rated voltage above 100 kV.

The manufacturer's data on tests performed in accordance with 8.4.2.3 shall show the maximum switching impulse residual voltage or shall state that the maximum switching impulse residual voltage does not exceed the specified maximum switching impulse residual voltage.

The voltage rating of the test specimen shall be 3 kV or more but need not exceed 6 kV. Repeated testing of a specimen is permissible provided the voltage-building capability is not degraded by the previous operations. The test specimen shall be at ambient room temperature before each measurement.

8.4.2.1 *Test circuit*

A distributed constant generator shall be used composed of N sections with series inductance L_i and shunt capacitance C_i such as:

Surge impedance of the generator $Z_G = \sqrt{L_i/C_i}$ is between 0,75 and 1,5 ohms per kV of specimen rating.

The time duration $T_D = 2 \sum_{i=1}^{i=N} \sqrt{L_i\ C_i}$ is greater than 2 000 µs.

The number of generator sections shall be equal to or greater than 10.

Added inductance L_T is connected in series between the generator and the specimen to be 3 to 3,5 mH per kV of specimen rating.

The generator charge voltage E_G in per unit of the test specimen peak voltage rating is equal to U_c of table 5.

8.4.2.2 *Measurements*

The maximum crest value of specimen residual voltage shall be measured after each initial 100 µs of specimen conduction using a high impedance voltage divider. The generator charging voltage shall be recorded.

> NOTE - The measurement of current may be desirable but it is not required in the evaluation of this test. The relationship of specimen maximum residual voltage and discharge current is affected by the type and components of the circuit as well as by the design of the specimen.

8.4.2.3 *Test procedure*

The first operation is to determine the specimen's maximum peak residual voltage. Measurements are made at increasing generator charge voltage from 1,0 per unit of the test specimen peak voltage rating. Increments shall not be greater than 0,25 per unit. The test voltage need not exceed 2,5 per unit. At least one specimen shall be tested within each charge level with two discharges at each level.

Measurements are then made on at least six additional new specimens. These shall be tested with two discharges applied to each specimen for three charge levels: two specimens at approximately the generator charge voltage that produced the maximum residual voltage as explained above and two each within ±0,25 per unit ranges of this generator charging voltage.

The switching impulse residual voltage as determined by this test is the average of the three highest values measured.

8.5 Current impulse withstand tests

8.5.1 *General*

Each of these tests shall be made in accordance with 7.1 and 8.1 on three new samples of complete arresters, arrester sections, or (where specified in 8.5.3.3) non-linear resistor elements only which have not been subjected previously to any tests except those specified for evaluation purposes. The rated voltage of the test samples shall be at least 3 kV and need not exceed 6 kV. If an arrester disconnector is built into the design of the arrester under consideration, these tests shall be made with the disconnector in operable condition.

8.5.2 *High-current impulse test*

Before the tests, the average dry power-frequency sparkover voltage is determined for each test sample as specified in 8.2.

The test consists of the application to each sample of two 4/10 current impulses with peak values as shown in table 4.

Table 4 - High-current impulse test

Arrester class (nominal discharge current) A		Peak value of high-current impulse kA
10 000	light and heavy duty	100
5 000	series A and B	65
2 500		25
1 500		10

The samples shall be permitted to cool between impulses to approximately ambient temperature. Both voltage and current shall be measured on each impulse and the voltage records on the same sample shall show no significant difference. The tolerances on the adjustment of the equipment shall be such that the measured values of the current impulses are within the following limits:

a) from 90 % to 110 % of the specified peak value;

b) from 3,5 µs to 4,5 µs for virtual front time;

c) from 9 µs to 11 µs for virtual time to half value on the tail;

d) the peak value of any opposite polarity current wave shall be less than 20 % of the peak value of the current;

e) small oscillations on the impulse are permissible provided their amplitude in the neighbourhood of the peak of the impulse is less than 5 % of the peak value. Under these conditions, for the purpose of measurement, a mean curve shall be accepted for determination of the peak value.

Following the second high-current impulse and after the test sample arrester has cooled to near ambient temperature, the power-frequency sparkover tests which were made before the high-current test are repeated for comparison.

8.5.3 *Long-duration current impulse test*

8.5.3.1 *General*

Before the long-duration current impulse test, the average dry power-frequency sparkover voltage (except where only non-linear resistors are used as specified in 8.5.3.3) and the residual voltage at nominal discharge current of each test sample are determined as specified in clauses 8.2 and 8.4 respectively.

All tests are performed with a generator of the distributed-constant type, the general principle of which is described in annex D. The circuit elements of the generator need not necessarily have identical values throughout all sections. If an auxiliary impulse generator is used to initiate the discharge of the distributed-constant generator, the stored energy of the former shall not exceed 0,5 % of the stored energy of the latter.

Each long-duration current impulse test consists of 20 discharge operations divided into four groups of five operations. Intervals between operations shall be 50 s to 60 s, and intervals between groups shall be 25 min to 30 min. Oscillographic records of the voltage across and current through the test sample shall be made on the first and twentieth operations of each test sequence.

Following the long-duration current impulse test and after the test sample has cooled to near ambient temperature, the power-frequency sparkover tests and the residual voltage tests which were made before the long-duration current impulse test are repeated for comparison.

8.5.3.2 *Heavy-duty 10 000 A arresters*

Arresters of this class may be fitted with current limiting gaps which do not permit the full rectangular current impulse to be maintained. Therefore, the characteristics of the generator, such as the number of sections, the capacitances and inductances of the generator elements, and the losses shall fulfil certain requirements and this shall be demonstrated by the following calibration procedure before the long-duration current impulse test on the sample arresters or sections.

The generator is charged to a suitable voltage, U_d, not less than 50 % of the specified charging voltage, U_c, and thereafter discharged through a low-inductance load resistor with a resistance, R, approximately equal to R_1. The values of U_c and R_1 are given in table 5 for five different arrester classes based on different discharge withstand capabilities.

Table 5 - Parameters for the long-duration current impulse test on heavy-duty 10 000 A arresters

Long-duration discharge classe	Load resistor value R_1 Ω	Virtual duration of peak µs	Charging voltage U_c kV (d.c.)
1	3,3 U_r*	2 000	3,0 U_r *
2	1,8 U_r	2 000	2,6 U_r
3	1,2 U_r	2 400	2,6 U_r
4	0,8 U_r	2 800	2,4 U_r
5	0,5 U_r	3 200	2,2 U_r

* U_r = rated voltage of the test sample, in kilovolts.

NOTE - The classes 1 to 5 of the above table correspond to increasing voltages and increasing discharge requirements. The selection of the appropriate discharge class is based on system requirements and is dealt with in Annex C.

The characteristics of the generator are considered correct if the peak value of the discharge current, I_d, is such that the value of the expression:

$$k = \frac{U_d}{2 \cdot I_d \cdot R}$$

lies between 0,95 and 1,05, U_d being expressed in kilovolts, I_d in kiloamperes and R in ohms, respectively. The current impulse shall be substantially rectangular, i.e. it shall fulfil the following requirements:

a) The virtual duration of the peak shall lie between 100 % and 120 % of the value specified in Table 5.

b) The virtual total duration shall not exceed 150 % of the virtual duration of the peak.

c) Oscillations or initial overshoot shall not exceed 10 % of the peak current value. If oscillations occur, a mean curve shall be drawn for the determination of the peak value.

d) If the current pulse is followed by a short pulse of opposite polarity, the peak value of the latter shall not exceed 10 % of the peak value of the former.

For the long-duration current impulse test on the sample arrester after completion of the foregoing calibration procedure, the load resistor is replaced by the test sample and the charging voltage is increased to U_c, if the value of k does not exceed 1,0 or kU_c, if k exceeds 1,0.

NOTES

1 The variation range permitted for the value of k is intended to include the manufacturing tolerances for the load resistor, and the deviation of the generator impedance from its ideal value, i.e. equal to R_1.

2 The prescribed small increase in charging voltage is intended to restore the prospective current to the required value when the sum of the load resistor value and the generator impedance exceeds 2 R_1.

(Note 3 to page 22)

NOTES *(continued)*

3 The load resistor value and the generator surge impedance will have to be approximately equal in order to obtain the specified substantially rectangular current impulse and to ensure that current reversal, if any, remains within the specified limit of 10 % of the main current impulse.

8.5.3.3 *10 000 A light-duty, 5 000 A and 2 500 A arresters*

The long-duration test is performed on the non-linear resistors only. No demonstration of the generator adjustment is required before the long-duration current impulse test on light-duty arresters.

The non-linear resistors of the test sample are paralleled or series-paralleled with other resistors (linear or non-linear) and subjected to the specified number of discharge operations of the generator. The number and resistance of the added resistors and the charging voltage shall be so chosen that the current impulse through the test sample shall have the substantially rectangular form defined in 8.5.3.2 with values of virtual duration of the peak of the impulse and peak current not less than those specified in table 6.

Table 6 - Requirements for the long-duration current impulse test on 10 000 A light-duty, 5 000 A and 2 500 A arresters

Arrester class A		Peak current A	Virtual duration of peak µs
10 000	light-duty	150	2 000
5 000	series A or B	75	1 000
2 500		50	500

8.6 Operating-duty test

This is a test in which service conditions are simulated by the application to the arrester of a stipulated number of specified current impulses while it is energized by a power supply of specified frequency, voltage, and impedance. Annex E describes a typical test-circuit which may be used.

The test shall be made in accordance with 7.1, 7.2 and 8.1 on three new samples of complete arresters or arrester sections which have not been subjected previously to any tests except those specified for evaluation purposes. The rated voltage of the test samples shall be at least 3 kV if the rated voltage of the arrester is not lower than this, and need not exceed 12 kV. If an arrester disconnector is built into the design of arrester under consideration, these tests shall be made with the disconnector in operable condition, see 8.8.

For arresters rated above 12 kV, it is usually necessary to make this test on an arrester section because of limitations of existing test facilities. It is important that the voltage across the gaps of the test sample and the follow-current through the sample represent as closely as possible the conditions in the complete arrester.

For arresters with uniform voltage distribution, the power-frequency test voltage to be applied to the test arrester section is the rated voltage of the complete arrester divided by the total number, n, of similar arrester sections. The arrester may be considered to have uniform voltage distribution if n times the power-frequency sparkover of the section is not more than 1,2 times the power-frequency sparkover of the complete arrester.

NOTE - Experience has shown that the voltage distribution due to the follow-current is generally more uniform than the voltage distribution at the instant of sparkover.

For arresters with non-uniform voltage distribution, the power-frequency test voltage shall be such that the voltage per gap in the sample section corresponds to the highest voltage per gap in the complete arrester. The test voltage shall be agreed to between manufacturer and purchaser. Guidance is given by the ratio of the sparkover voltage of the section to sparkover voltage of the complete arrester. To maintain the correct follow-current value, it is necessary that the ratio of the value of the non-linear resistors of the section to the value of the non-linear resistors of the complete arrester is the same as the ratio of the test voltage to the rated voltage of the complete arrester. To fulfill this condition, it may be necessary to select a combination of gap and resistor elements different from the combination normally used in the complete arrester. If the gaps are not all of the same construction, it may be necessary to test more than one arrangement using the maximum voltage per gap for each construction.

Before the operating-duty test, the average dry power-frequency sparkover voltage and the residual voltage at nominal discharge current of each sample are determined as specified in 8.2 and 8.4 respectively.

The test sample including grading components is either assembled in a housing of the same design as that to be used in service or mounted in a sealed enclosure. The enclosure shall be designed to reproduce the same heat capacity and thermal losses, with special reference to the axial heat transference, as would occur if the actual arrester were tested. Details of the design of the test enclosure, mounting and connection arrangements, together with the results of any tests carried out to demonstrate the thermal equivalence of the tests and service arrangement, shall be given.

The arrester or arrester section is connected across a power supply having a frequency within the range of 48 Hz to 62 Hz. The impedance of the power source shall be such that during the flow of follow-current, the peak value of power-frequency voltage, measured at the arrester terminals, does not fall below the peak value of the rated voltage of the test specimen and after the interruption of follow-current the peak voltage does not exceed the peak value of the rated voltage by more than 10 %.

NOTE - This increase is allowed only to permit use of test equipment of reasonable power capacity and should not be taken as justification for exceeding the rated voltage of arresters in service.

An impulse generator is connected across the arrester through a spark-gap and is adjusted to generate an 8/20 current impulse having a peak value equal to the nominal discharge current of the arrester. The first test impulse shall be timed to occur approximately 60° electrical before voltage peak of the power-frequency voltage wave.

If follow-current is established consistently, the test is made with this timing. If follow-current is not established consistently with this timing, the timing is retarded in approximately 10° steps towards voltage peak until follow-current occurs consistently, at which timing the test is made. The polarity of the initiating current shall be the same as that of the half cycle of power-frequency voltage during which it occurs. Twenty impulses are applied in four groups of five impulses. The interval between impulses shall be 50 s to 60 s. The interval between groups shall be 25 min to 30 min to allow the test sample to cool to near ambient temperature unless longer periods are specified by the manufacturer before the test. The rated voltage of the test sample shall be maintained across the test sample for at least one cycle of the power-frequency voltage preceding, and for 10 s following each application of the current impulse. These durations may be increased to allow sufficient time for voltage stabilization, measurement and scatter in switching times, etc. For arresters declared by the manufacturer to be capable of withstanding the rated voltage for the duration of the operating-duty test, the test sample shall remain energized at the rated voltage of the test sample between impulses, between groups of impulses and for at least 10 s following the last discharge of the last group.

In the case of high arc voltage (current-limiting) gaps, the timing described above would not necessarily represent the most onerous condition and an appropriate modification of the timing to obtain the highest value of follow-current shall be made.

The tolerances on the adjustment of the testing equipment for the current impulse shall be such that the measured values are within the following limits:

a) between 90 % and 110 % of the specified peak value;

b) from 7 µs to 9 µs for the virtual front time;

c) from 18 µs to 22 µs for the virtual time to half value of the tail.

Follow-current must be established by each test impulse and the test sample must interrupt the follow-current each time. Permanent oscillograms are required of the power-frequency voltage and follow-current associated with each discharge of each group. These oscillograms shall show the voltage across and the current through the test sample throughout the period from one complete cycle of the power-frequency voltage before application of the impulse to 10 complete cycles after the final interruption of the follow-current. Final interruption of the follow-current shall occur not later than at the end of the half-cycle following that in which the impulse is applied. There shall be no further sparkover of the test sample in any subsequent half-cycle. The peak value and wave shape of the current impulse may be determined either during the operating-duty test or during a preliminary test in which the power-frequency voltage may be switched off; no more than three impulses shall be applied to the test sample during this calibration.

Following the operating-duty test and after the test sample has cooled to near ambient temperature, the measurement of the power-frequency sparkover and the residual voltage, which were made before the operating-duty test, are repeated for comparison.

8.7 Pressure-relief tests

8.7.1 *General*

When the arrester is fitted with a pressure-relief device, it shall be tested in accordance with this clause. Each test shall be made on a test sample contained in a new housing. One such sample shall be tested at high-current (see 8.7.2), and a separate sample at low-current (see 8.7.3).

In order to initiate the flow of current inside the test sample arrester, all of the series gaps and non-linear resistor elements shall be bypassed by a fuse wire which will melt within the first 30 electrical degrees after test current initiation. The fuse wire bypassing the non-linear resistor elements shall follow the contour in close proximity to the surface of the resistors.

The test sample shall be mounted to simulate installation conditions that are in accordance with the recommendations of the manufacturer. The upper end shall be terminated with the end configuration of another unit or the terminal cap, whichever is the more restrictive to pressure-relief. The base shall be level with the top of an approximately circular enclosure which is at least 30 cm high and which shall encircle the test sample and be concentric therewith. The diameter of the enclosure shall equal the sample diameter plus twice the sample height, with a minimum diameter of 1,8 m. The test sample is deemed to have passed the test if the housing remains intact or if it breaks non-explosively and if all parts of the sample are contained within the circular enclosure.

The power-frequency of the test supply shall be not less than 48 Hz and not over 62 Hz.

8.7.2 *High-current pressure-relief tests*

The test sample shall be the longest unit of each different design of arrester as defined in 8.1, and this test shall be regarded as demonstrating compliance with the requirements by arresters of all rated voltages of the same design provided that:

a) the design is one where both series gaps and non-linear series resistors are incorporated in the unit in proportion of the voltage rating of the unit. Where the arrester design is such that different units of the arrester contain differing ratios of series gaps to non-linear series resistors, the test procedure shall be subject to agreement between the manufacturer and the purchaser;

b) each unit of the arrester employs a housing of the same cross-sectional dimensions. If the arrester incorporates units having different designs of porcelain housing, i.e., the base unit is of larger dimensions, the longest units of each design shall be tested.

The short-circuit capacity of the power source shall be high enough so that the r.m.s. value of the a.c. component of the current shall not fall below 75 % of the specified value in 0,2 s when the arrester is short-circuited by a link of negligible impedance. The short-circuit power factor of the test circuit shall be not higher than 0,1 (X/R = 10 or more).

Tests shall be made on a single-phase circuit and at a voltage of 77 % to 107 % of the rated voltage of the arrester, whenever possible. However, it is expected that tests on high-voltage arresters will be made at a testing station which will not have sufficient power to make the tests on all arresters at 77 % of the rated voltage. Accordingly, two alternative procedures for making the high-current pressure-relief test are given below in 8.7.2.1 and 8.7.2.2.

NOTE - The 77 % voltage corresponds to the voltage applied to an arrester whose voltage rating is 75 % of the system phase-to-phase voltage (i.e., at a location having a 75 % coefficient of earthing). For locations having an 80 % or 100 % coefficient of earthing, the phase-to-earth voltage would be 72 % or 58 % of the arrester voltage rating respectively.

The tests are made to demonstrate compliance with one of the pressure-relief classes given in table 7. The test current shall be allowed to flow for at least 0,2 s during tests on the sample, although shorter times may be adequate for tests to measure the prospective current and to adjust the circuit.

Table 7 - Requirements for pressure-relief tests

Pressure-relief class		Arrester class			Minimum prospective symmetrical fault current A (r.m.s.)
80		10 000	A	heavy-duty	80 000
63		10 000	A	heavy-duty	63 000
50		10 000	A	heavy-duty	50 000
40	(A)	10 000	A	light or heavy duty	40 000
20	(B)	10 000	A	light or heavy duty	20 000
10	(C)	10 000	A	light or heavy duty	10 000
16	(D)	5 000	A	series A	16 000
5	(E)	5 000	A	series A	5 000

8.7.2.1 *High-current tests at 77 % rated voltage*

The prospective current shall first be measured by making a test with the arrester shunted by a link of negligible impedance. The circuit parameters and timing of the closing switch shall be such that the r.m.s. value of the a.c. component of the current shall equal or exceed the appropriate value for the pressure-relief class given in table 7 and the peak value of the current in the first major loop shall be at least 2,6 times the minimum prospective symmetrical fault current.

The shunting link is then removed and the sample arrester is tested using the same circuit parameters and timing.

The resistance of the restricted arc inside the arrester will reduce the a.c. component and peak value of the current. This does not invalidate the test since this test is made with at least normal service voltage and the effect on the test current is the same as would be experienced during a fault in service. The arrester is credited with having passed a test in which the fault current is the r.m.s. value of the a.c. component of the prospective current measured in the test with the arrester shunted by a link of negligible impedance.

8.7.2.2 *High-current tests at less than 77 % rated voltage*

When tests are made with a test-circuit voltage appreciably less than 77 % of the voltage rating of the test sample, the resistance of the internal arc is disproportionally high compared with the impedance of the test-circuit, so that the a.c. component and peak value of the current may be significantly less than if the test were made at 77 % of the voltage rating. Therefore, it may be incorrect to credit the arrester with the prospective current value. For this reason, when tests are made at less than 77 % of the rated voltage of the arrester, the peak value of the first major loop of current through the arrester shall be at least 2,6 times the prospective symmetrical fault current from table 7 and appropriate to the pressure-relief class. Additionally, the r.m.s. value of the a.c. component shall be at least equal to this current.

It is not essential to make a preliminary test with a link of negligible impedance shunting the arrester, but allowance should be made in selecting the test-circuit parameters for the effect of the internal arc resistance which will vary with the length and restriction of the arc within the arrester housing, and this may necessitate increasing the prospective current, particularly when the voltage of the test circuit is appreciably lower than 77 % of the voltage rating of the arrester.

8.7.3 *Low-current pressure-relief tests*

The test sample arrester may be any rating of the design under consideration and this test demonstrates compliance of all ratings of the same design. With a test-circuit voltage equal to 77 % to 107 % of test sample rating, the circuit parameters are adjusted so as to produce a current through the test sample of 800 A, r.m.s. (±10 %) measured at approximately 0,1 s after start of current flow. The current shall flow until venting occurs and the decrement during the test shall not exceed 10 % of that measured initially.

NOTE - Should an arrester fail to vent during the test, care should be taken before approaching the arrester to relieve the internal pressure which may still be very high even when cool.

8.8 Tests of arrester disconnectors

8.8.1 *General*

These tests shall be made on arresters which are fitted with arrester disconnectors or on the disconnector assembly alone if its design is such as to be unaffected by the heating of adjacent parts of the arrester in its normal installed position.

The test sample shall be mounted in accordance with the manufacturer's published recommendations using the maximum recommended size and stiffness and the shortest recommended length of connecting lead. In the absence of published recommendations, the conductor shall be hard-drawn bare copper, approximately 5 mm in diameter and 30 cm long, arranged to allow freedom of movement of the disconnector when it operates.

8.8.2 *Current impulse withstand and operating-duty tests*

As noted in 8.5 and 8.6 these tests are made at the same time as the tests on the arrester in the case of built-in disconnectors. In the case of disconnectors designed for attachment to an arrester or for insertion into the line or ground lead as an accessory, these tests may be made separately or in conjunction with tests on arrester samples. The disconnector must withstand, without operating, each of the following tests, three new samples being used for each different test:

8.8.2.1 *High-current impulse test*

This test is made in accordance with 8.5.1 and 8.5.2 with the peak current corresponding to the highest classification of arrester with which the disconnector is designed to be used.

8.8.2.2 *Long-duration current impulse test*

This test is made in accordance with 8.5.1, 8.5.3.1 and 8.5.3.3 with the peak current and duration corresponding to the highest classification of arrester (see table 6) with which the disconnector is designed to be used.

8.8.2.3 *Operating-duty test*

This test is made in accordance with 8.6, with the sample disconnector in series with a test sample section of the arrester design having the highest follow-current of all the arresters with which it is designed to be used.

8.8.3 *Disconnector operation*

8.8.3.1 *Time/current curve test*

Data for a time/current curve are obtained at three different symmetrically initiated current levels, i.e., 20 A, 200 A and 800 A, r.m.s. (±10%), flowing through test sample disconnectors with or without arresters as required by 8.8.1.

For tests on disconnectors affected by internal heating of the associated arresters, the non-linear resistors and series gaps must be bypassed with a bare copper wire 0,08 mm to 0,13 mm in diameter, in order to start the internal arcing.

For tests on disconnectors unaffected by the operation of the associated arrester, the arrester, if it is used for mounting the disconnector, shall have its non-linear resistors and series gaps shunted or replaced by a conductor of size sufficient to ensure that it will not be melted during the test.

The test voltage may be any convenient value so long as it is sufficient to maintain full current flow in the arc over the arrester elements, and sufficient to cause and maintain arcing of any gaps upon which operation of the disconnector depends. The test voltage may not exceed the rated voltage of the lowest-rated arrester with which the disconnector is designed to be used.

The parameters of the test circuit are adjusted, with the test sample shunted by a link of negligible impedance, to produce the required value of current. The closing switch shall be timed to close the circuit within a few electrical degrees of voltage crest so as to produce nearly symmetrical current. An opening switch may be provided with provision for adjusting the time of current flow through the test sample. This switch may be omitted when accurate control over the current duration is not necessary. After the test-circuit parameters have been adjusted, the link shunting the test sample is removed.

The current flow is maintained at the required level until operation of the disconnector occurs. At least five new samples shall be tested at each of the three current levels.

The r.m.s. value of current through the specimen and the duration to the first movement of the disconnector is plotted for all the samples tested. The time/current characteristic curve of the disconnector is drawn as a smooth curve through the points representing maximum duration.

Alternatively, for disconnectors which operate with an appreciable time delay, the time/current curve test may be made by subjecting the test samples to controlled durations of current flow to determine the minimum duration for each of the three current levels which will consistently result in successful operation of the disconnector. If successful operations of the disconnector occur in five tests out of five trials, or, if one unsuccessful test occurs, five successful out of five additional trials occur, the point is used for the time/current curve.

8.8.3.2 *Evaluation of disconnector performance*

There must be clear evidence of effective and permanent disconnection by the device. If there be any question of this, a power-frequency voltage equal to 1,2 times the rated voltage of the highest rated arrester with which the disconnector is designed to be used shall be applied for 1 min without current flow in excess of 1 mA, r.m.s.

Table 8 - Maximum impulse sparkover (see 8.3) and residual voltages (see 8.4)
Values referred to U_r

Rated arrester voltage U_r kV r.m.s.	Maximum standard lightning impulse sparkover voltage kV peak		Front-of-wave lightning impulse			Maximum switching impulse sparkover voltage kV peak	Maximum residual voltage at nominal discharge current kV peak	
			Nominal steepness of wavefront kV/µs	Maximum sparkover voltage kV peak				
	10 000 A heavy-duty arresters	2 500 A, 5 000 A, 10 000 A light-duty arresters		10 000 A heavy-duty arresters	2 500 A, 5 000 A, 10 000 A light-duty arresters	10 000 A heavy-duty arresters	10 000 A heavy-duty arresters	2 500 A, 5 000 A, 10 000 A light-duty arresters
$0,15 < U_r \leq 0,3$	-	8,0 U_r	10	-	12,0 U_r	-	-	8,0 U_r
$0,3 < U_r \leq 0,6$	-	6,0 U_r	10	-	7,5 U_r	-	-	6,0 U_r
$0,6 < U_r \leq 1,2$	-	5,0 U_r	10	-	6,0 U_r	-	-	5,0 U_r
$1,2 < U_r \leq 10$	-	3,6 U_r	8,3 U_r	-	4,15 U_r	-	-	3,60 U_r
$10 < U_r \leq 120$	2,80 U_r	3,33 U_r	7,0 U_r	3,20 U_r	3,85 U_r	-	2,80 U_r	3,33 U_r
$120 < U_r \leq 200$	2,60 U_r	3,00 U_r	6,0 U_r	3,00 U_r	3,45 U_r	-	2,60 U_r	3,0 U_r
$200 < U_r \leq 300$	2,60 U_r	-	1 300	3,00 U_r	-	2,75 U_r	2,60 U_r	-
$300 < U_r \leq 420$	2,50 U_r	-	1 500	2,90 U_r	-	2,45 U_r	2,50 U_r	-
$U_r > 420$	2,50 U_r	-	2 000	2,90 U_r	-	2,45 U_r	2,50 U_r	-

Annex A
(normative)

Abnormal service conditions

The following are typical abnormal service conditions which may require special consideration in the manufacture or application of surge arresters and have to be called to the attention of the manufacturer.

1) Temperature in excess of +40 °C or below −40 °C.

2) Application at altitudes higher than 1 000 m.

3) Fumes or vapours which may cause deterioration of insulating surface or mounting hardware.

4) Excessive contamination by smoke, dirt, salt spray or other conducting materials.

5) Excessive exposure to moisture, humidity, dropping water or steam.

6) Explosive mixtures of dust, gases, or fumes.

7) Abnormal vibration or mechanical shocks.

8) Unusual transportation or storage.

9) Live washing of arrester.

10) Nominal system frequency below 48 Hz or above 62 Hz.

Annex B
(informative)

Typical information given with enquiries and tenders

B.1 Information given with enquiry

B.1.1 *System data*

- highest system voltage;
- frequency;
- maximum voltage to earth under system fault conditions (earth fault factor or system of neutral grounding);
- maximum duration of the earth fault;
- maximum value of temporary overvoltages and their maximum duration (earth fault, loss of load, ferroresonance)
- insulation level of equipment to be protected;
- short-circuit current of the system at the arrester location.

B.1.2 *Service conditions*

a) Normal conditions (see 4.4).

b) Abnormal conditions:

  - ambient conditions (see 4.4.2 and annex A);
  - natural pollution level (see IEC 71-2);
  - possibility of generator overspeeding (voltage versus time characteristics);

  - nominal power-frequency of the system other than 48 Hz to 62 Hz;
  - load rejection and simultaneous earth faults;
  - formation during faults of a part of the system with an insulated neutral in a normally effectively earthed neutral system;
  - incorrect compensation of the earth fault current.

B.1.3 *Arrester duty*

a) Connection to system:

  - phase-to-earth;
  - neutral-to-earth;
  - phase-to-phase.

b) Type of equipment being protected:

- transformers (directly connected to a line or via cables);
- rotating machines (directly connected to a line or via transformers);

- reactors;
- HF-reactors;
- other equipment of substations;
- gas insulated substations (GIS);
- capacitor banks;
- cables (type and length), etc.

c) Maximum length of high voltage conductor between arrester and equipment to be protected (protection distance).

B.1.4 *Characteristics of arrester*

- rated voltage;
- power-frequency sparkover voltage (minimum value);
- lightning impulse sparkover voltage (maximum value);
- front-of-wave sparkover voltage (maximum value);
- switching impulse sparkover voltage (minimum and maximum values);
- nominal lightning discharge current and residual voltage;
- for 5 000 A arresters whether series A or B;
- for 10 000 A arresters whether light or heavy duty;
- for heavy duty arresters, the respective long-duration discharge class;
- pressure-relief class (short circuit capability);
- length and shape of creepage distance of arrester housing. Selected on the basis of service experience with surge arresters and/or other types of equipment in the actual area.

B.1.5 *Additional equipment and fittings*

- metal enclosed arresters;
- type of mounting: pedestal, bracket, hanging (in what position) etc., and if insulating base is required for connection of surge counters. For bracket-mounted arresters indicate whether bracket is to be earthed or not;

- mounting orientation if other than vertical;
- earth lead disconnector if required;
- cross-section of connection leads.

B.1.6 *Any special abnormal conditions*

For example: very frequent operation.

B.2 Information given with tender

All information in B.1.4 and B.1.5 and in addition:

- clearances;
- mounting specifications;
- pressure-relief function;
- type of arrester terminals and permissible conductor size;
- maximum permissible length of lead between arrester and surge counter and earth;
- dimensions and weights;
- cantilever strength;
- switching residual voltage.

Annex C
(informative)

Selection of the long-duration discharge class of heavy-duty arresters

Heavy-duty arresters are normally applied where line discharge capability is required.

NOTE - An application guide on arresters has been published as IEC Publication 99-1A (1965). This application guide is under revision and will be published as IEC 99-5.

The test requirements shown in table 5 of 8.5.3.2 are based on the duty involved in discharging transmission lines with the following characteristics, table C.1, which are considered to cover the majority of applications:

Table C.1 - Transmission line characteristics

Long-duration discharge class	Approximate range of system voltages kV	Approximate line length km	(miles)	Approximate line surge impedance Ω	Approximate overvoltage factor (p.u.)*
1	Up to 245	300	(190)	450	3,0
2	Up to 300	300	(190)	400	2,6
3	Up to 420	360	(225)	350	2,6
4	Up to 525	420	(260)	325	2,4
5	Up to 765	480	(300)	300	2,2

* The base for the per unit values is the peak of the highest system line-to-neutral voltage.

Normally, the long-duration discharge class is based on the corresponding system voltage in accordance with table C.1. However, where system characteristics vary appreciably from those in the table, arresters of one discharge class may be used at system voltages corresponding to higher or lower classes. In such cases a study of the particular circumstances is recommended. In general, the arrester should not be used in situations where the gaps and non-linear resistors are submitted to the energy or the current developed during the discharge of switching surges exceeding those developed in the long-duration tests performed on these components. At lower voltages the energy may be the predominant requirement and at higher voltages the current.

As shown in table C.1 system parameters requiring consideration in determining the severity of the duty imposed during the discharge of switching surges are:

- line length;
- line surge impedance;
- level of overvoltage developed (overvoltage factor).

A further parameter to be considered is the rated arrester voltage in relation to system voltage. Other parameters and system conditions are also of importance but as the test requirements do not, for practical reasons, give consideration to these, they are not dealt with here.

Annex D
(informative)

Typical circuit for a distributed-constant impulse generator for the long-duration current impulse test according to 8.5.3

It is the purpose of this annex to give the principle of a suitable test circuit for use in the long-duration current impulse test and to describe the function of the various circuit components rather than to specify a standard test-circuit which should be used in all tests.

The requirements of wave shape, duration, charging voltage, load resistor, interval between impulses, etc., are given in the test specification.

The exact method by which these requirements are met is immaterial. There are many possible variations both in the arrangement of the circuit and in the choice of values for the various components. Figure D.1 shows a simplified diagram of a distributed-constant impulse generator. The surge impedance of the generator is determined by:

$$Z = \sqrt{\frac{L}{C}}$$ when neglecting the resistance.

The number of *LC* sections of the generator will normally be about ten to produce an acceptable waveshape. To limit the oscillations at the beginning and the end of the peak of the wave, it may be necessary to increase the inductances at both ends of the generator as well as to introduce parallel resistors, *R*, to compensate the reduced front steepness caused by the increased inductances.

The triggering gap can be a simple switch. However, if the generator charging voltage is insufficient to sparkover the arrester sample, a small auxiliary impulse generator may be required. In that case, both the distributed-constant impulse generator and the auxiliary impulse generator must be separated from the test sample by triggering gaps.

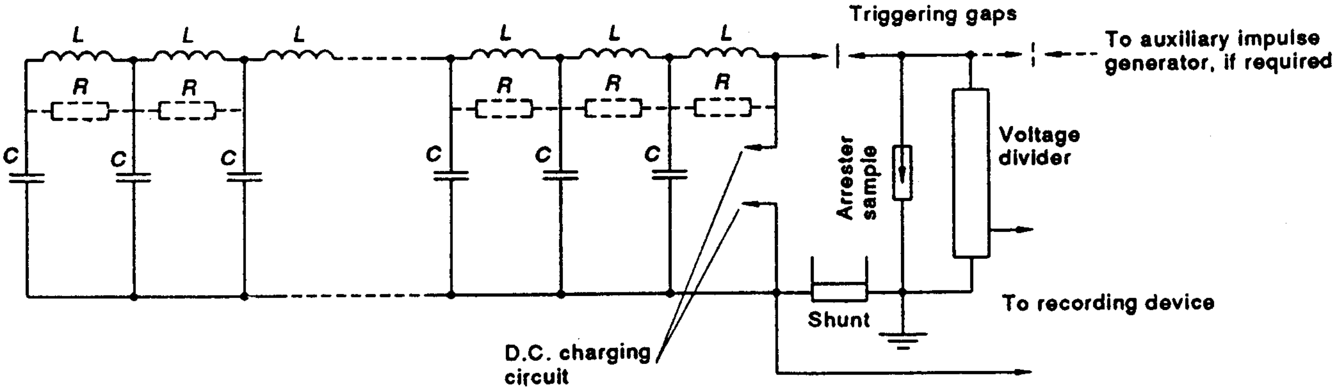

Figure D.1 - Typical circuit for a distributed-constant impulse generator for the long-duration impulse test

The current through and the voltage across the test sample should be recorded.

As required in 8.5.3 the waveshape shall be checked by a calibration procedure using a load resistor, the value of which should be very close to that of the generator surge impedance. Otherwise, the requirements with respect to the waveshape will not be fulfilled.

The design of the distributed-constant impulse generator should be such as to permit the inductance and capacitance to be changed readily. Moreover, a generator of adequate voltage permits alteration of the test sample rating so as to suit the surge impedance. However, it should be noted that the sample rating can only be altered in steps equal to the lowest voltage rating of the arrester sections used in the particular arrester design.

Annex E
(informative)

Typical circuit for operating-duty test according to 8.6

It is the purpose of this annex to suggest a suitable test-circuit (figure E.1) for use in the operating-duty test and to describe the function of the various circuit components rather than to specify a standard test-circuit which should be used in all tests. The requirements for the operating-duty test, such as the power-frequency voltage, the characteristics of the initiating current impulse, and the timing of the initiating impulse with respect to the power-frequency voltage wave are described in 8.6. The exact method by which these requirements are met is not important. There are many possible variations both in the arrangement of the circuit and in the choice of values for the various components.

The test sample is connected directly across the power-frequency supply, usually a transformer, although this is not essential. An impulse generator, shown as a two-stage circuit although it may be a single-stage circuit if adequate, is connected to the arrester through a resistor *R*, an inductor *L* and spark-gaps G_1 and G_2. The waveshape of the current impulse is controlled by selecting suitable values for *C*, *R*, and *L*. A low-resistance non-inductive shunt R_3 and a voltage divider V.D. are shown for the measurements of current and voltage respectively. A shunt R_4 is shown in the leads from the power transformer for recording the follow-current.

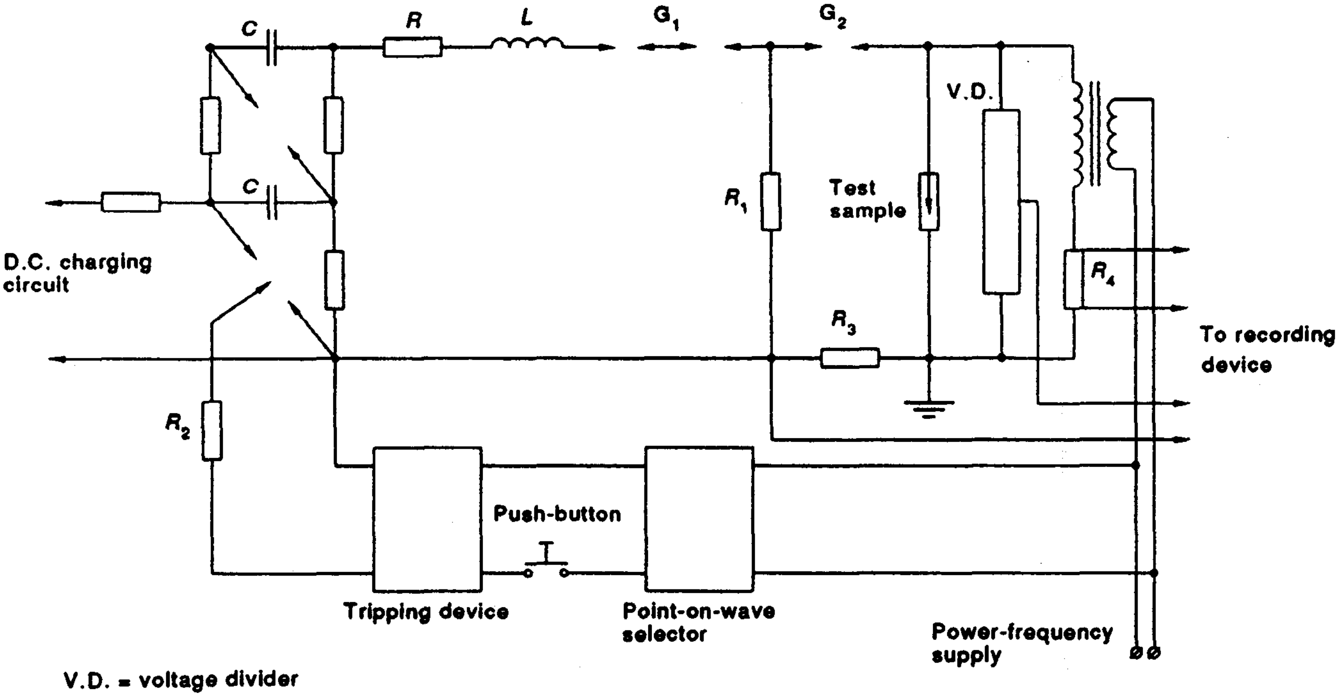

Figure E.1 - Typical test-circuit diagram for operating-duty test

The spark-gap which isolates the impulse generator from the power circuit may be of various forms. In the type of gap shown, the resistor R_1, if used, may be of the order of a megohm and serves to maintain a point in the multiple spark-gap at earth potential when no current is flowing. The part G_1 of the gap does not, therefore, have any of the power-frequency voltage across it and can be made to spark over at any point in the cycle. The part G_2 of the gap is made as small as is consistent with its ability to withstand the power-frequency voltage. The part G_1 is intended to interrupt any power-frequency current flowing to the impulse generator after the end of the impulse, and it is to assist in this that a multiple construction is shown. If the gap remains conducting after the end of the impulse, there may be an interchange of energy between the capacitance of the impulse generator and the power source which will disturb the test procedure. Damage to the impulse generator may also result from the continued flow of power-frequency current.

The power-frequency voltage may be recorded across a voltage divider or a voltage transformer.

The impulse generator shall be tripped at the correct instant on the power-frequency voltage wave. This may be accomplished by means of a synchronous spark-gap or by a point-on-wave selector, as shown in figure E.1, through a tripping device. This applies a high-voltage pulse to the centre electrode of the three-electrode gap in the impulse generator. A high resistance, R_2, prevents appreciable impulse current flowing in the tripping circuit.

The tripping of the impulse generator may be initiated by means of a push button or any means which sets in operation the recording system and trips the impulse generator at the selected instant on the power-frequency voltage wave.

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